Magnetic Field Distortions due to Electronics in the Mu2e Tracker

Potential use of 2D Hall Probes to measure the Alignment of a Magnetic Field

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Mu2e experiment

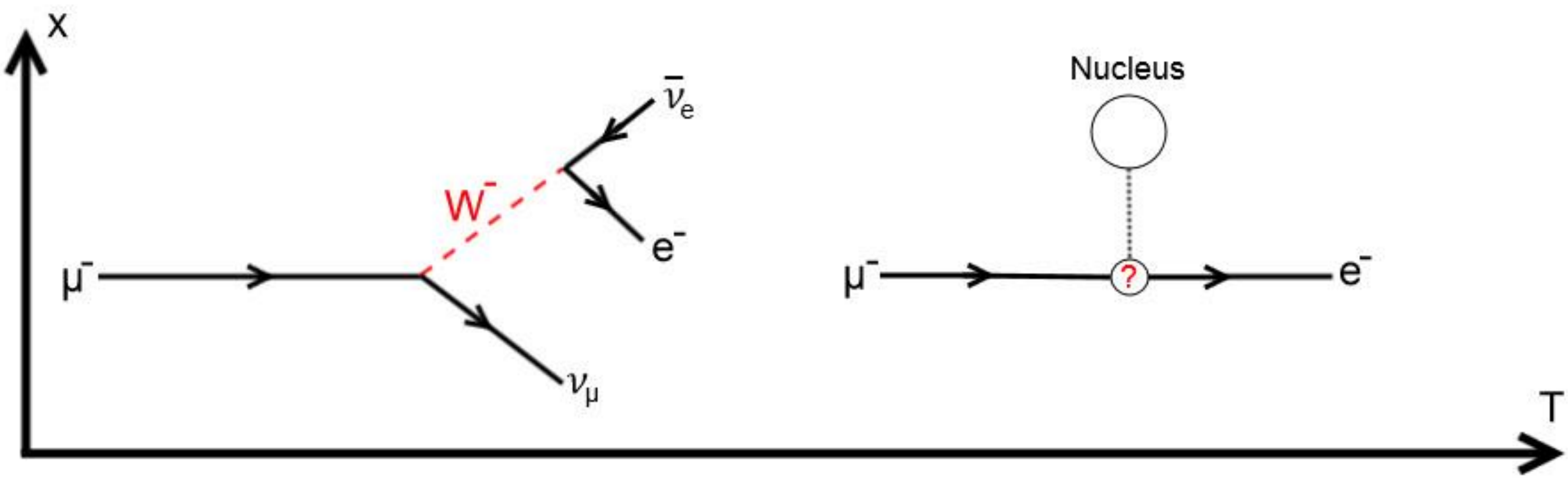
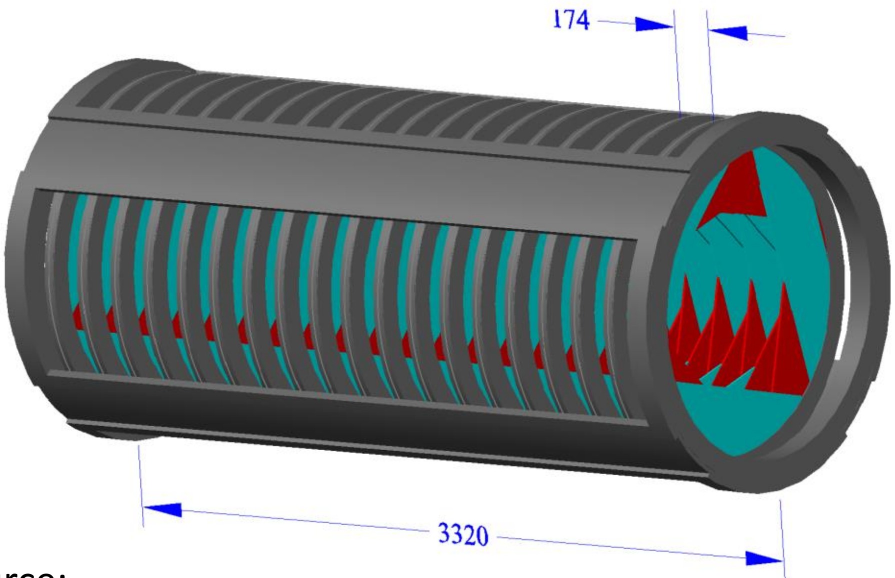


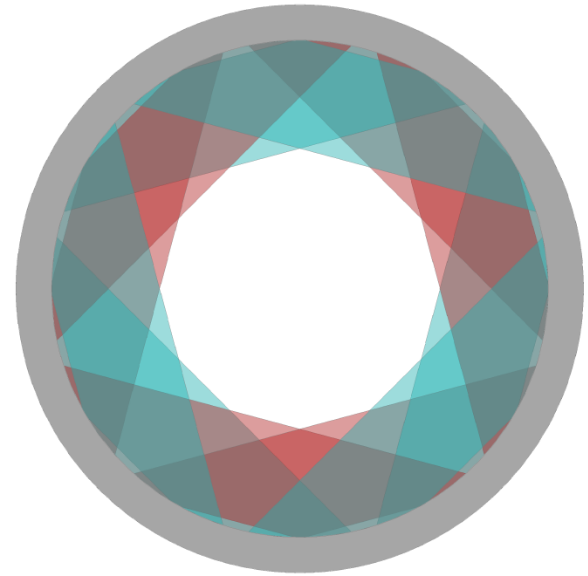
Figure 1: RHS: -The most common μ −decay

LHS: -Decay being tested with Mu2e experiment;

If seen it would push the boundaries of the Standard Model and if not, rule out other possibilities

Basic structure of the tracker





Source:
Mu2e
Doc888
Figures 4,6,7

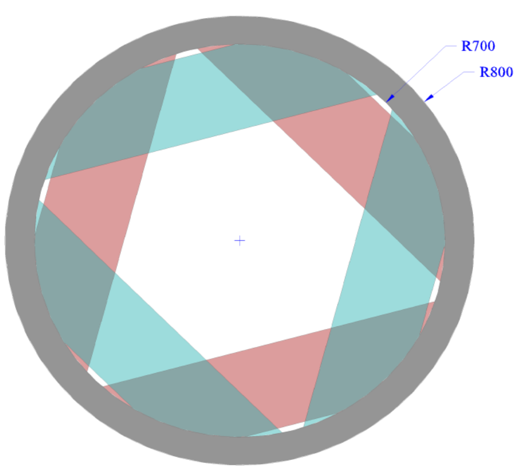


Figure 2:

TL: Assembled tracker

TR: 1 of the 18 stations

BL: Plane consisting of 6 panels

Sketch of the situation

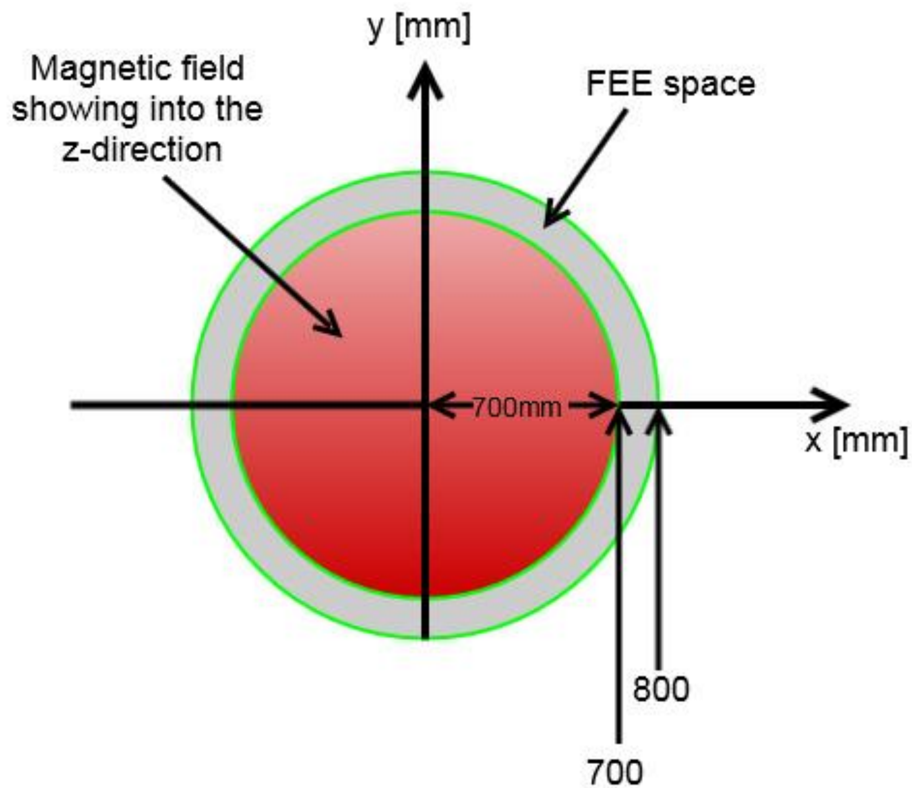


Figure 3: Sketch of the situation illustrating the position of the FEE (Front end electronics) space in relation to the magnetic field concerned

General principal to test whether electronics are magnetic

1. Fix electronic component to metal rod

2. Apply field of 1T

3. Set readings of Hall probes to 0

4. Slide component into the field
   (1cm from the Hall probes)

5. Read off distortion: Should be less than 1G

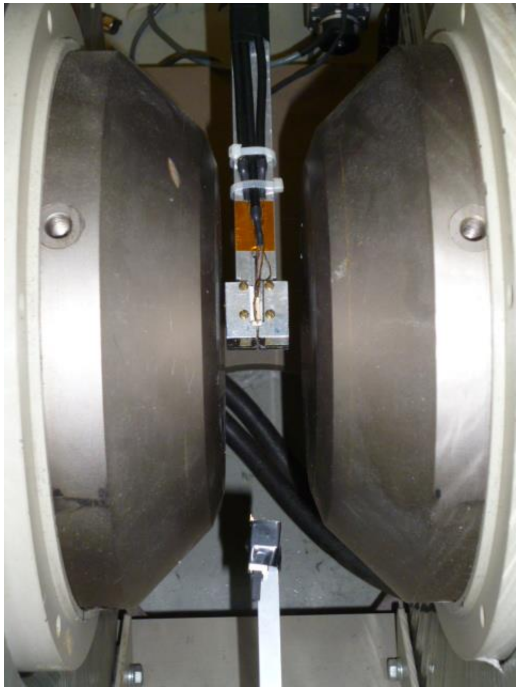


Figure 4: The 3D Hall probe in-between the two poles of the magnet and one of the transducers approaching

Results

- Distortions for most components seemed very small $\Rightarrow$ I decided it is safe enough to enter them by hand and see whether there is a change in Magnetic field
- There wasn't apart from one case:

The Transducer!!!

The Transducer

- Changed the field at 1cm distance by up to 15G
- Only changed the field by 0.7G at already 4 cm, but we have more than one transducer!
- Therefore we had to find a model

Sketch of the situation

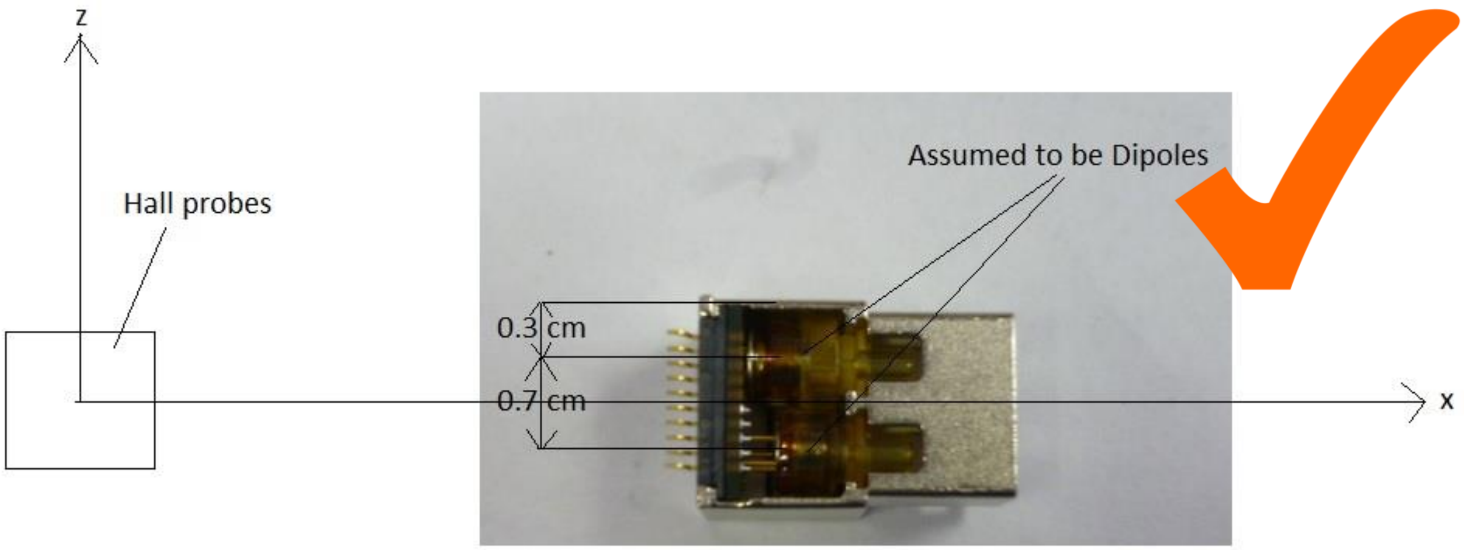


Figure 5: Sketch of the measurement situation with the y - axis going into the page. The magnetic field applied shows into the z – direction.

We tested whether the two packaging's for the photo elements could act as dipoles

Position of the transducers

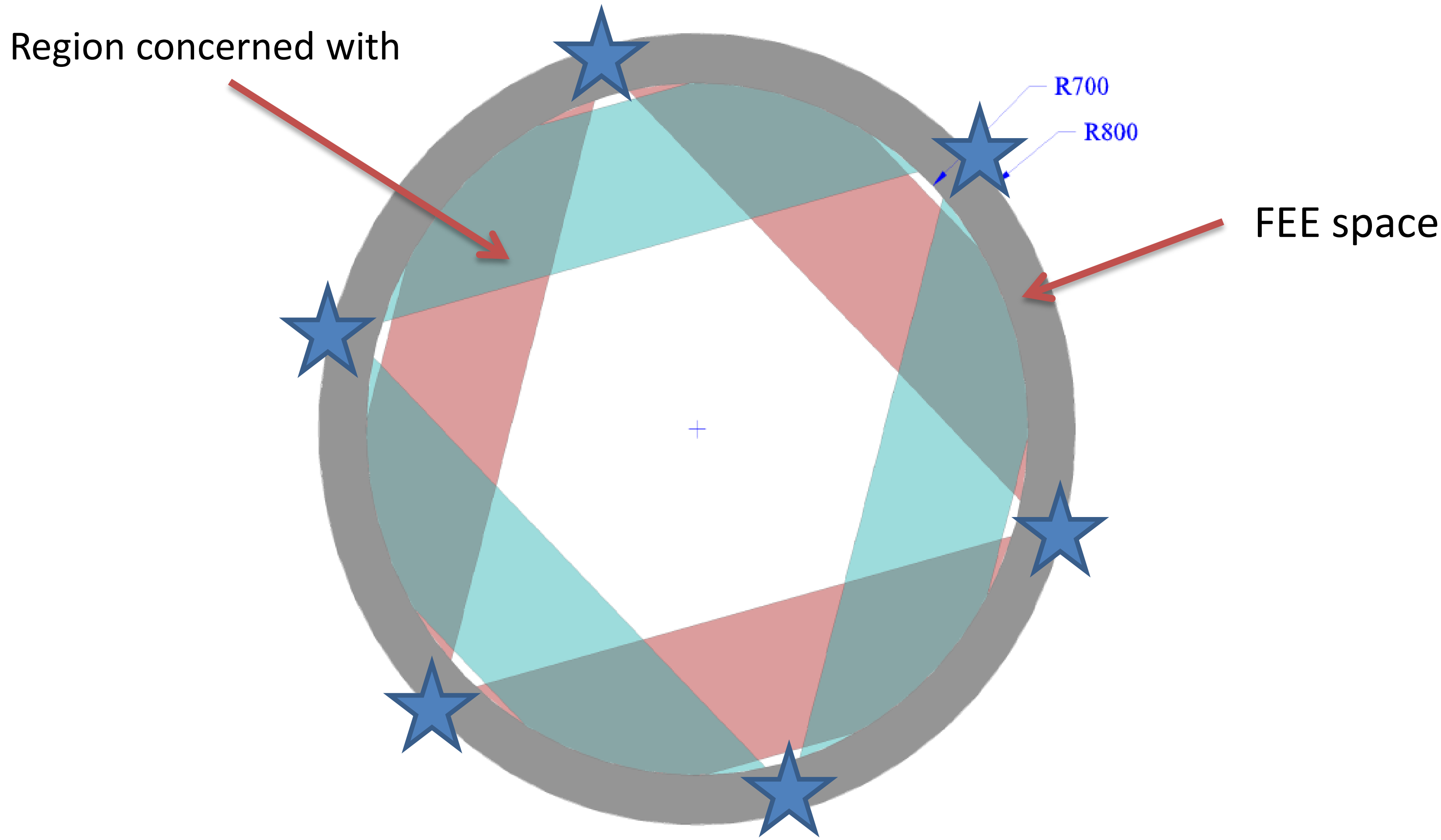


Figure 6: Positions of the transducers within the tracker. Note there will be two transducers positioned at each star

Do we have to worry?

- Model in Mathematica:
- Maximum Magnitude of the field in the region concerned:

0.086G

- This is under our specification of 1G

Conclusion

- Most of the components do not seem to distort the field at all (upper limit of distortion is 0.05G at 1 cm distance)
- The distortions from the transducers are an exception: They will distort the field by a considerate amount if not placed at the outer part of the FEE space

Importance of Alignment with the Magnetic Field

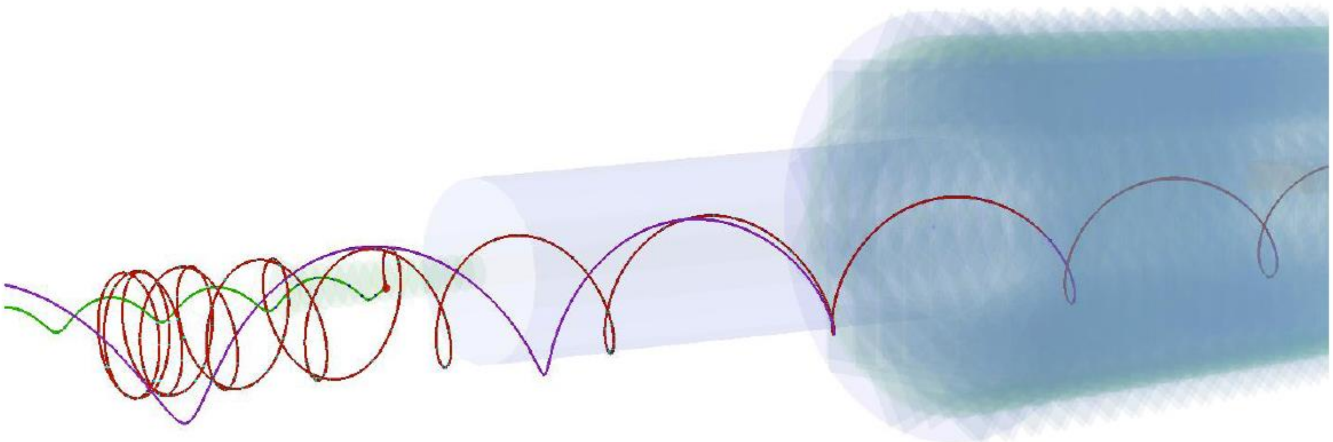


Figure 7: Muon (green) converting to an electron (red)
(source: Mu2e CDRv14 Figure 9.19)

- Charged particles follow helical trajectories; radius determines the momentum
- Misalignment of panels ⇒ 'smeared' observed particle position ⇒ lower overall observed efficiency of event production

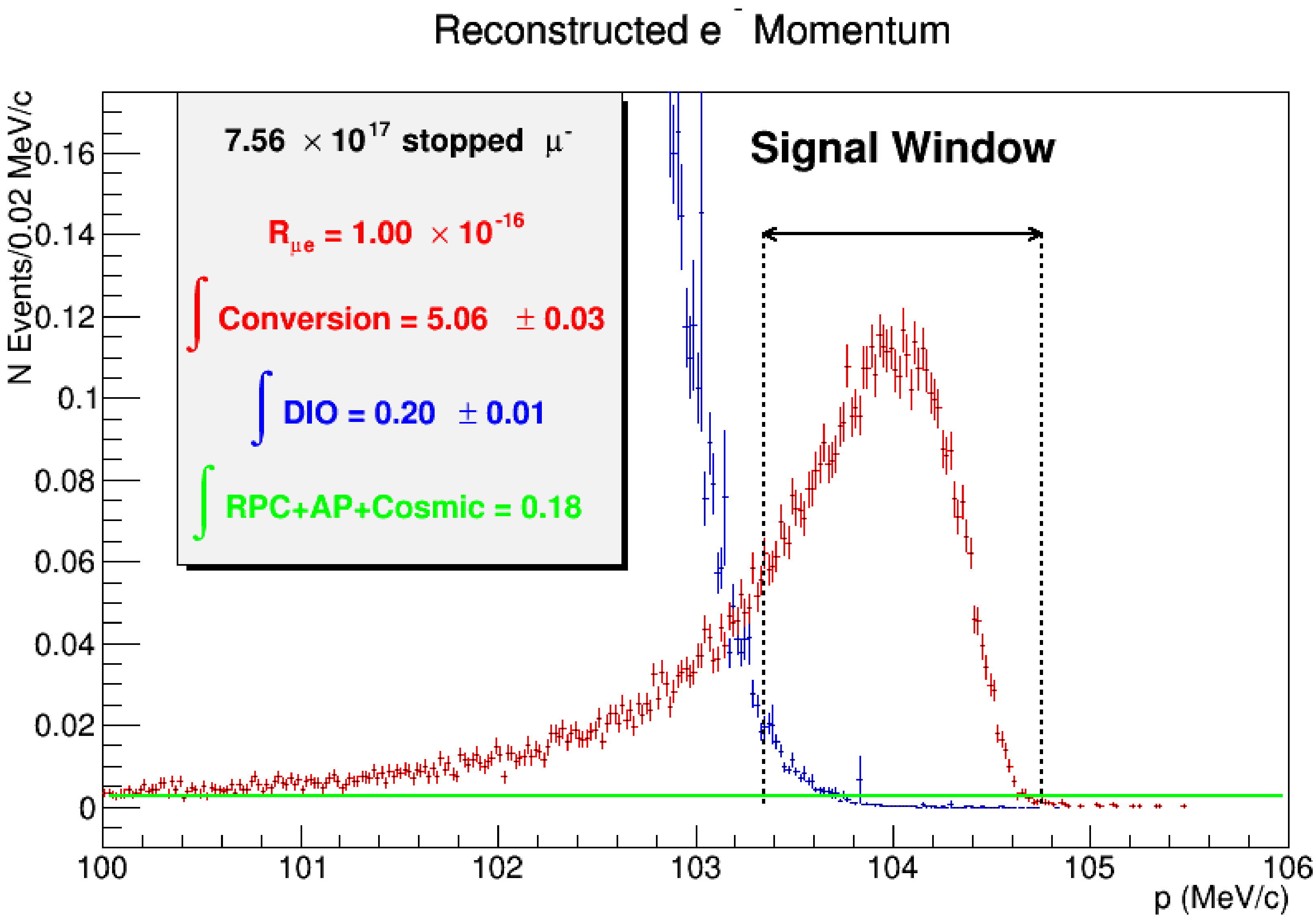


Figure 8: # of Events vs Momentum, Blue - normal muon decay, green - all other backgrounds, red - the expected signal (source: mu2e-docdb document 2936-v3,slide 31)

Monitoring alignment with a 2D Hall probe

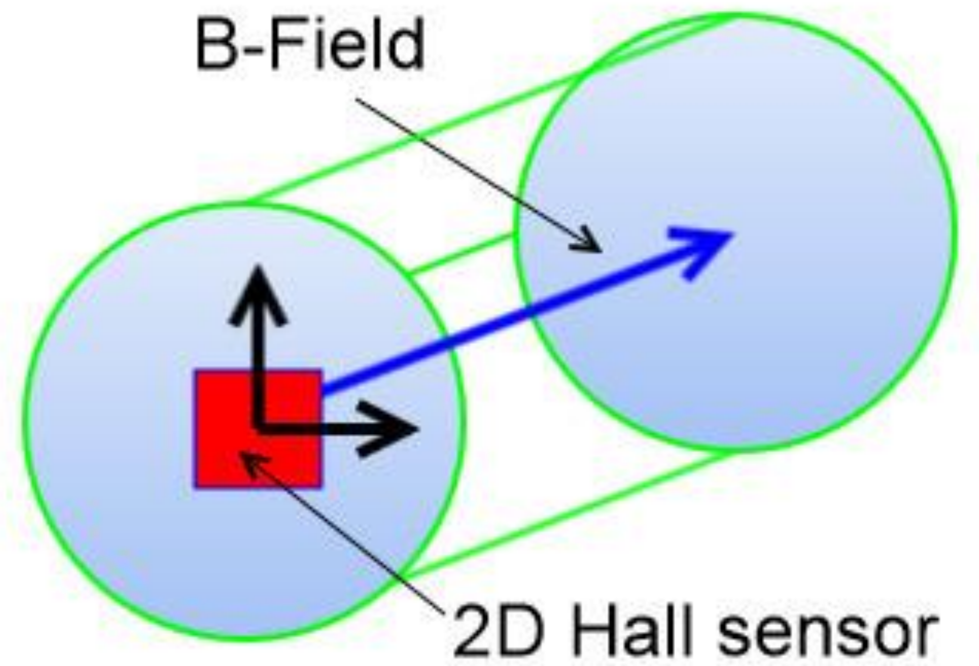


Figure 9: Sketch of a 2D Hall sensor measuring the x*- and* y*-direction (black thick arrows), while there is a B field in the* z*-direction (blue arrow)*

As long as the field is aligned with the Hall sensor, the reading won't change with the strength of the field ⇒ can detect misalignment

A suitable candidate

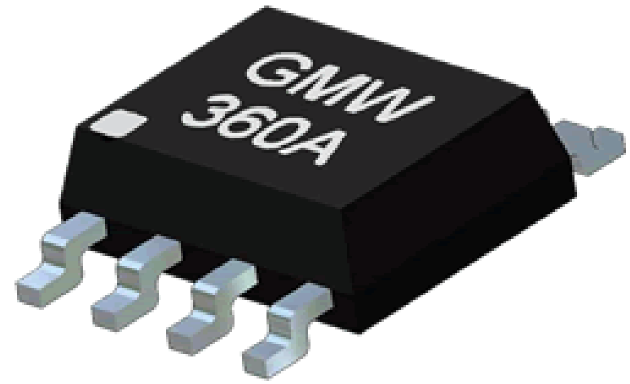
Figure 10: Sentron Angle Sensor, 2SA-10G probe

*Dimensions: 5mm*6mm*

Cost: 6.40$

Measurements up to 800G

Accuracy of about 1mV ≊ 0.21G



Field of the tracker is 1T ⇒can detect changes of 1.2 mDegrees (0.21G $= \sin\theta$ *10,000G)*

Has been tested before in a very similar set up

(I.B. Vasserman et al, „Magnetic Measurements and Tuning of Undulators for the aps fel project", published in the proceedings of the 1990 particle accelerator conference, New York, 1999)

Potential problems and solutions

- Accuracy of Alignment of Hall sensors
- Time dependence
- Temperature dependence
- Potential solution: Use two solenoids to measure the magnetic field

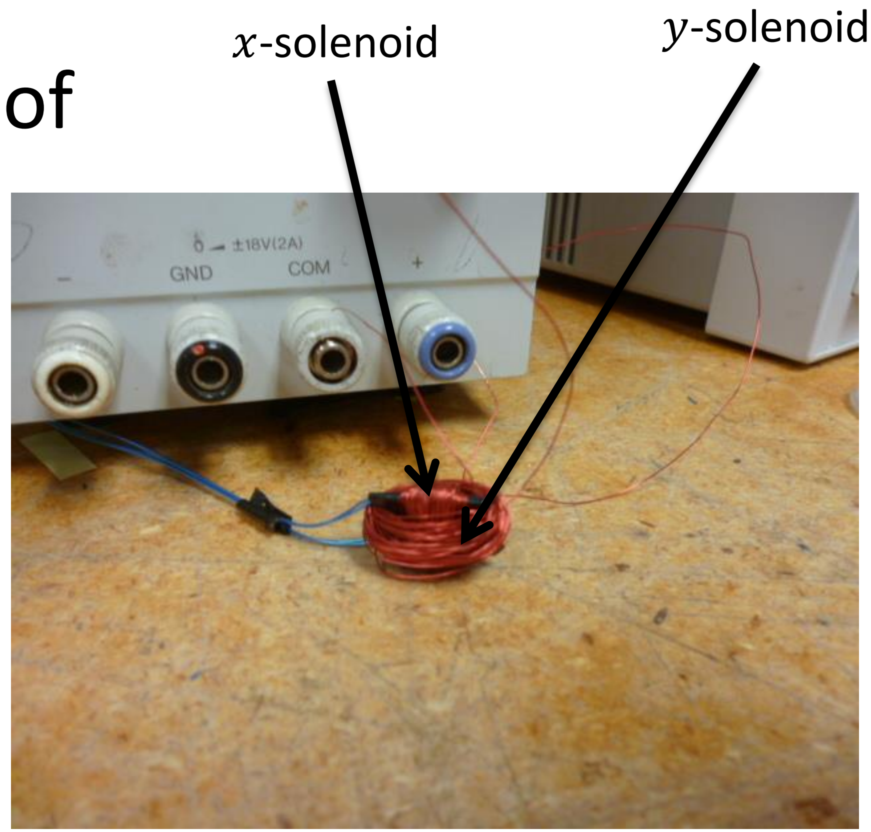


Figure 11: Hall probe with 2 solenoids

B in *x* vs I using solenoid 1

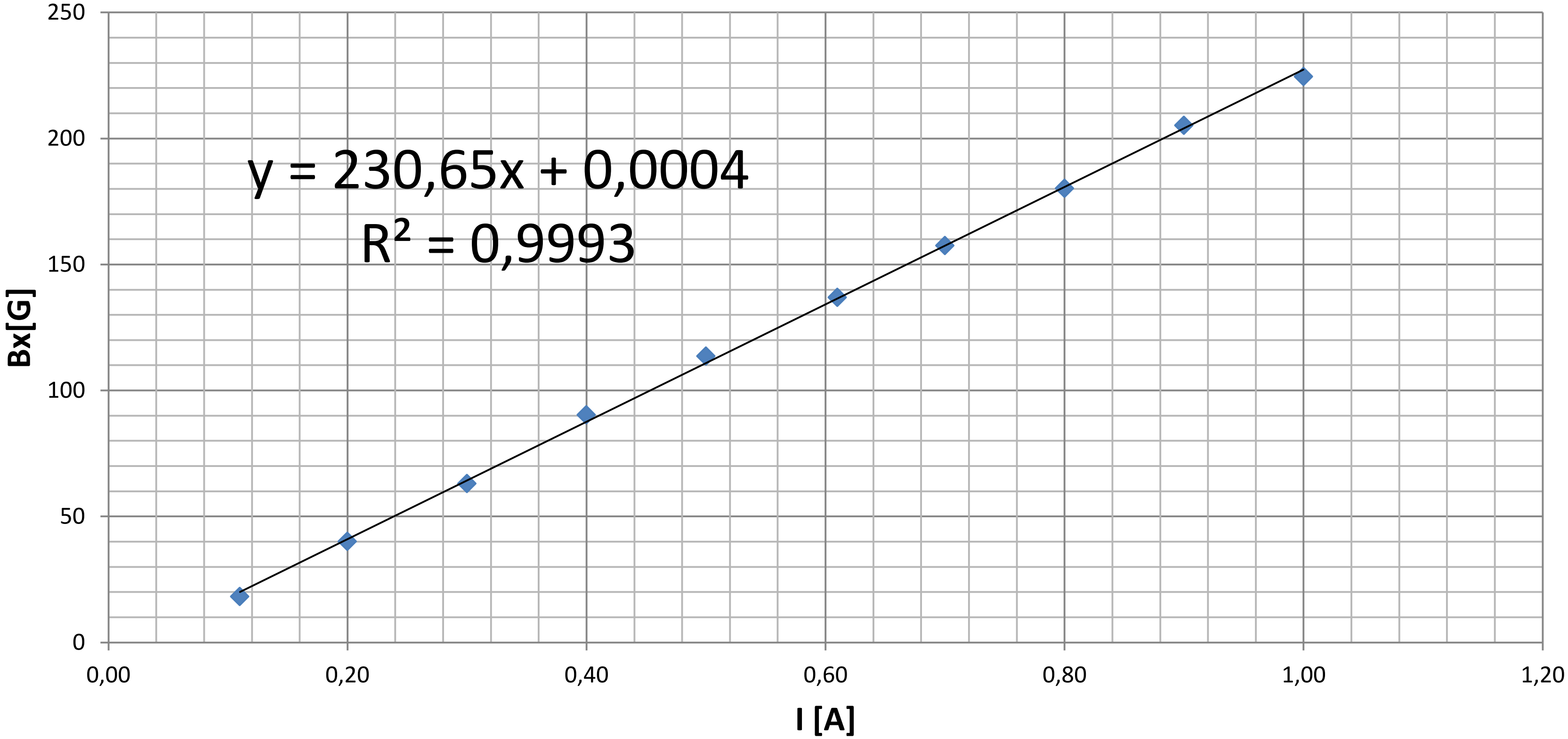


Figure 12: B in x vs I using solenoid 1

Note: The solenoid wasn't perfectly aligned therefore a small field was measured in the *y*-direction

Future Challenges

- 2^{nd} solenoid creates a smaller magnetic field
- The coils heat up and therefore change the reading (even at a 0 field)
- Methods to align the probe (calibration)
- Want to make set up smaller
- Check for radiation damages
- What about magnetic field distortions?

Backup

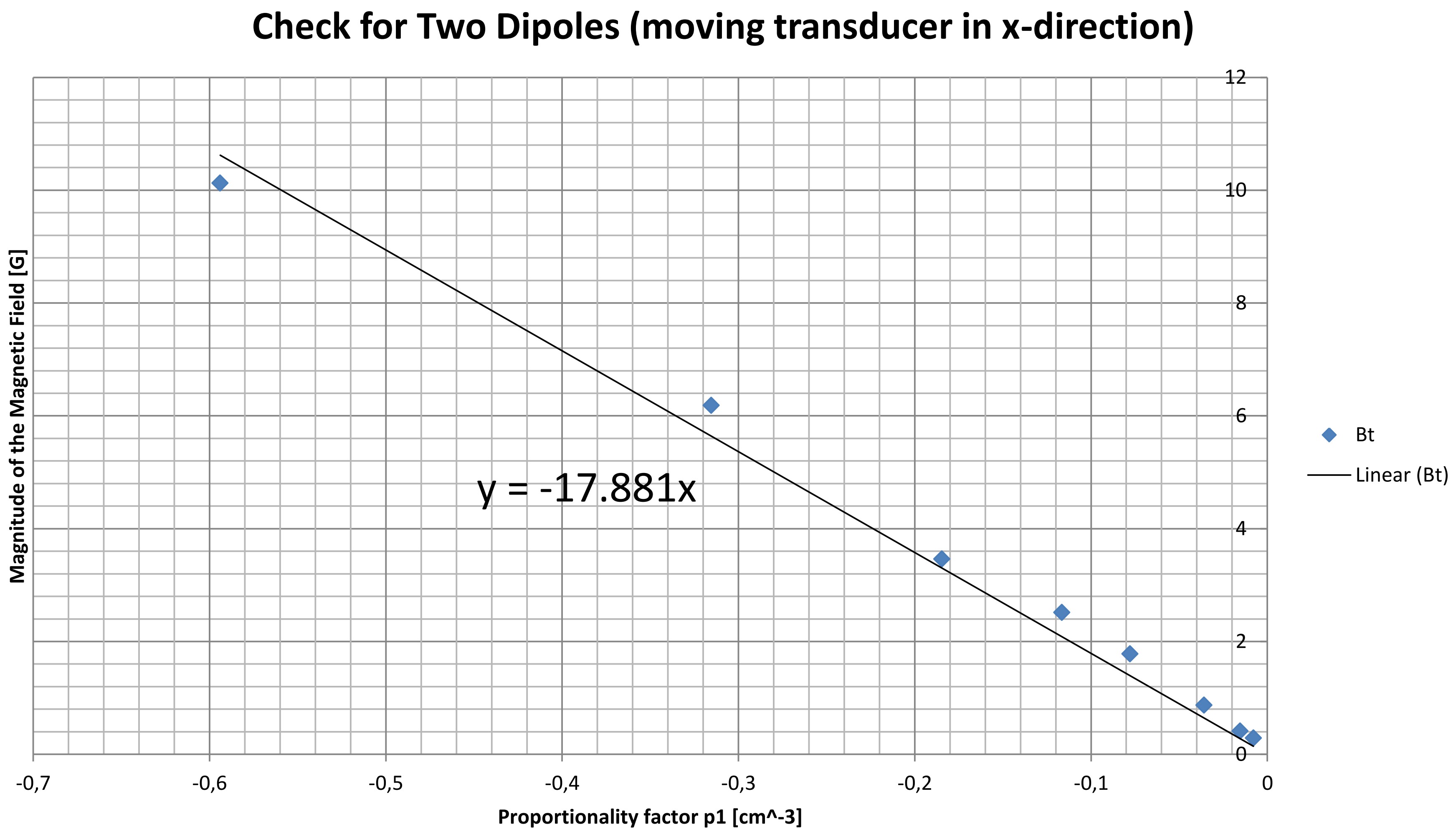


Figure 12: Check for Two Dipoles with

$$B_t = \frac{\mu_0 m}{2\pi} p_1 \approx -17.9\ p_1$$

Magnetic field distortions in panel plane positioned in the middle of the tracker

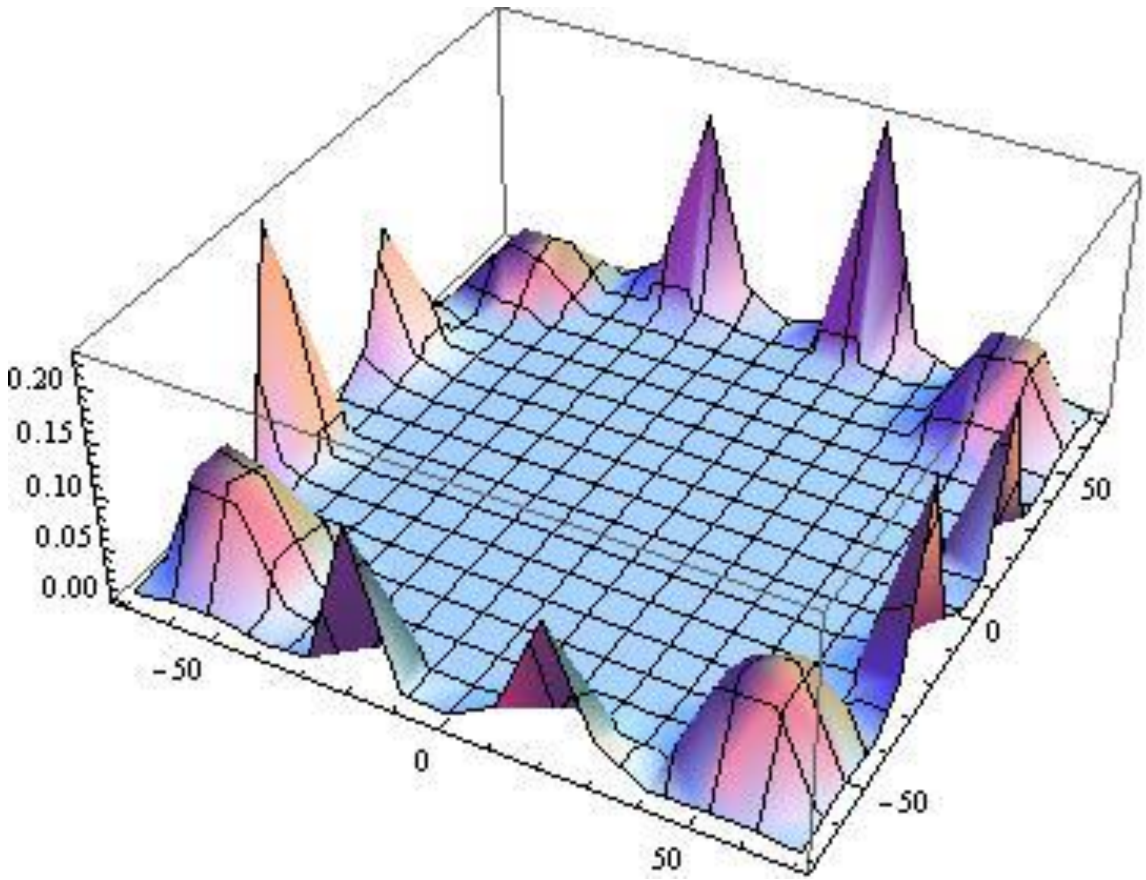
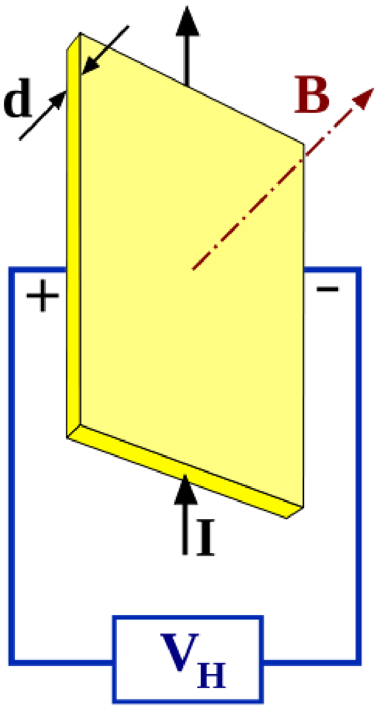


Figure 14: Magnetic field distortions for a panel plane in the middle of the tracker, magnitude plot

Hall Effect



Source: Wikipedia

How it works:

-Current flows in direction perpendicular to magnetic field, forcing electrons to one side of the wire

- This forms a potential difference which varies with the field strength and can be read into a DAQ

$$qvB = qE \quad \text{(1) Magnetic force = Force from V gradient}$$

$$I = \rho e v_d A \quad \text{(2) Current, where } \mathrm{v_d} \text{ is drift velocity}$$

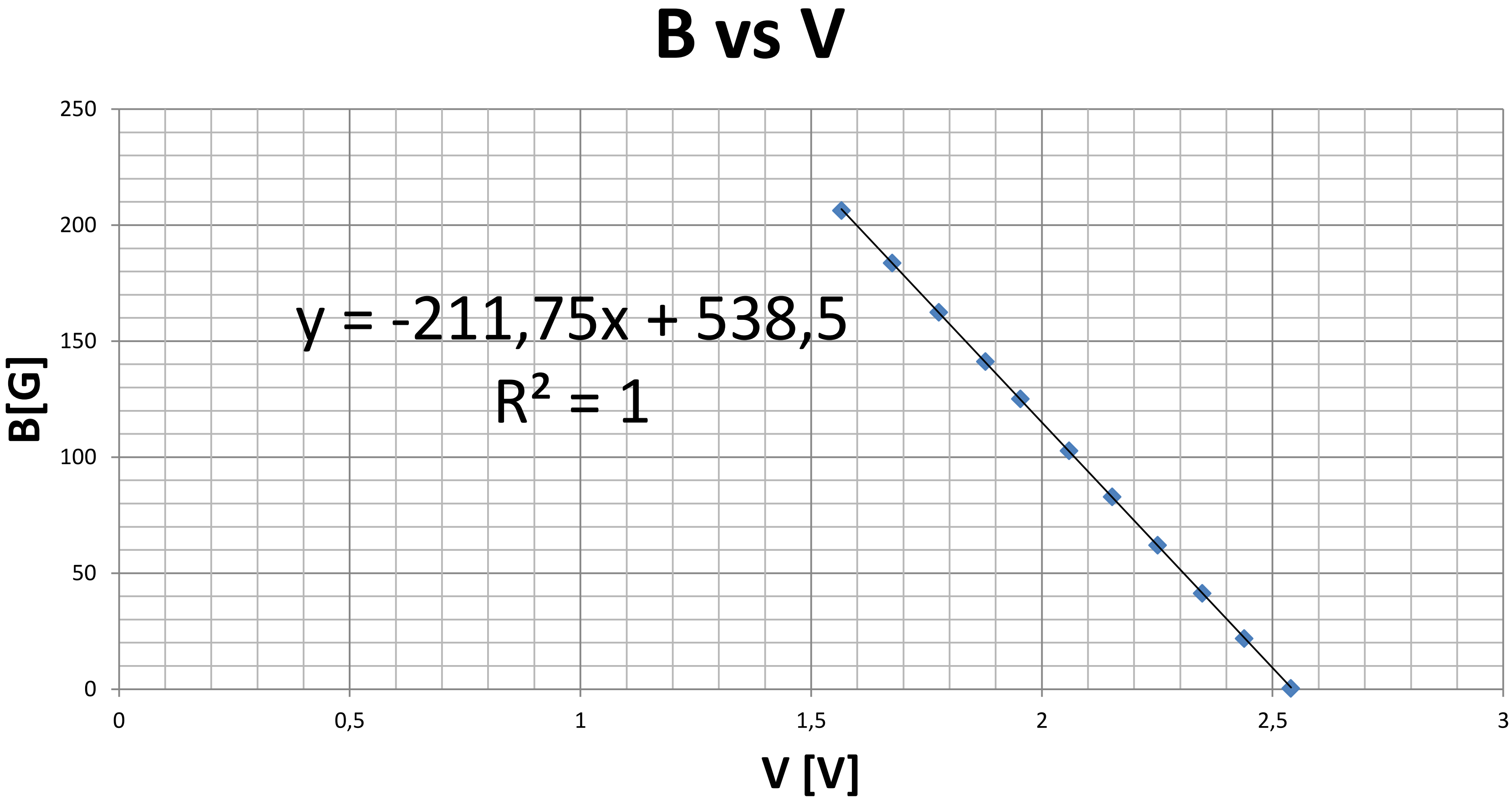
$$\mathrm{E} = \frac{\mathrm{V_H}}{\mathrm{w}} \quad \text{(3) From defn. of } \mathrm{E} = \nabla \mathrm{V}$$

$$= \frac{I \cdot B}{\rho e A} \quad \text{from (1) and (2)}$$

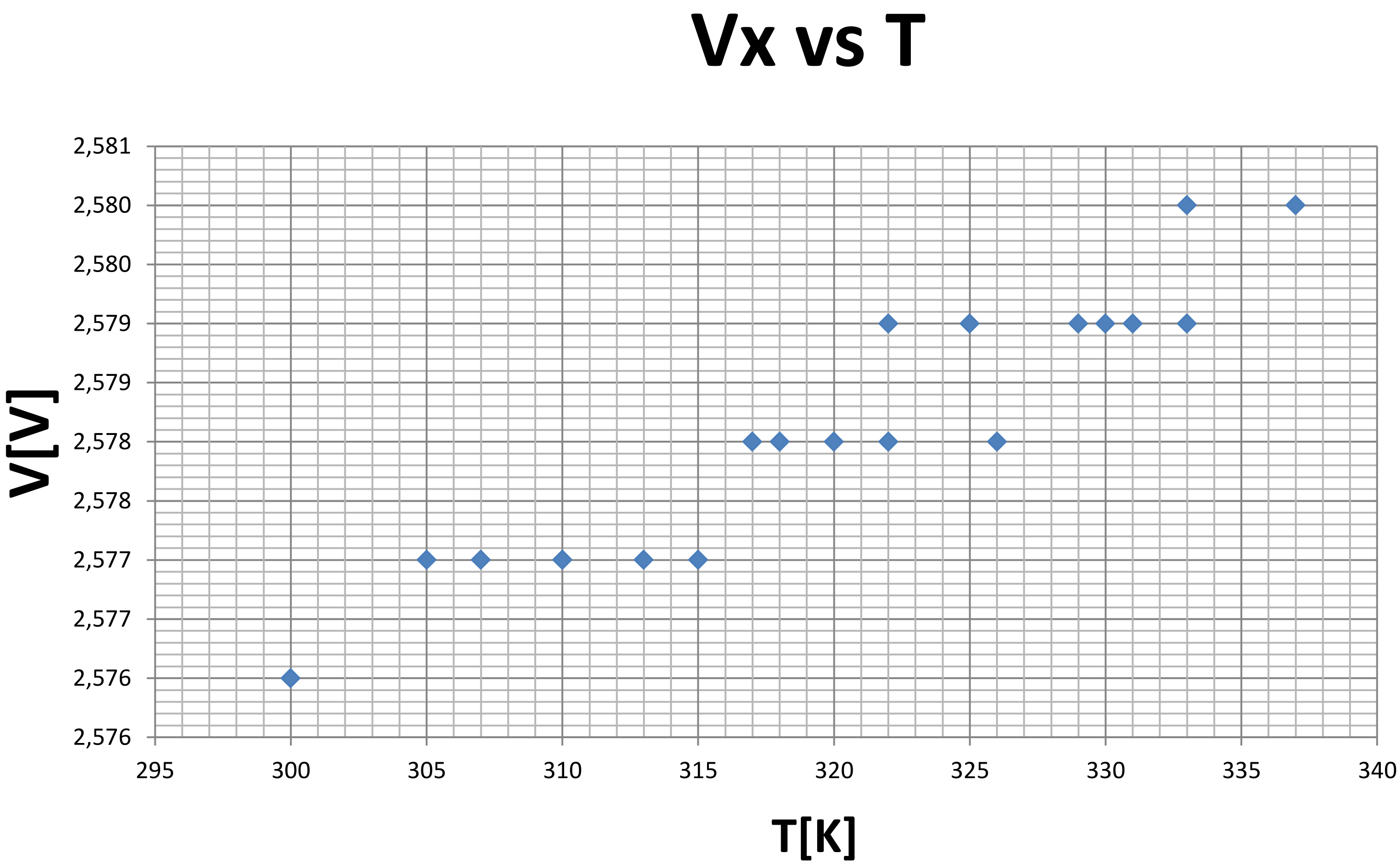
$$\Rightarrow \mathrm{V_H} = \frac{I \cdot B}{\rho e d}$$

A conveniently linear effect by which to measure the projection of the B field!

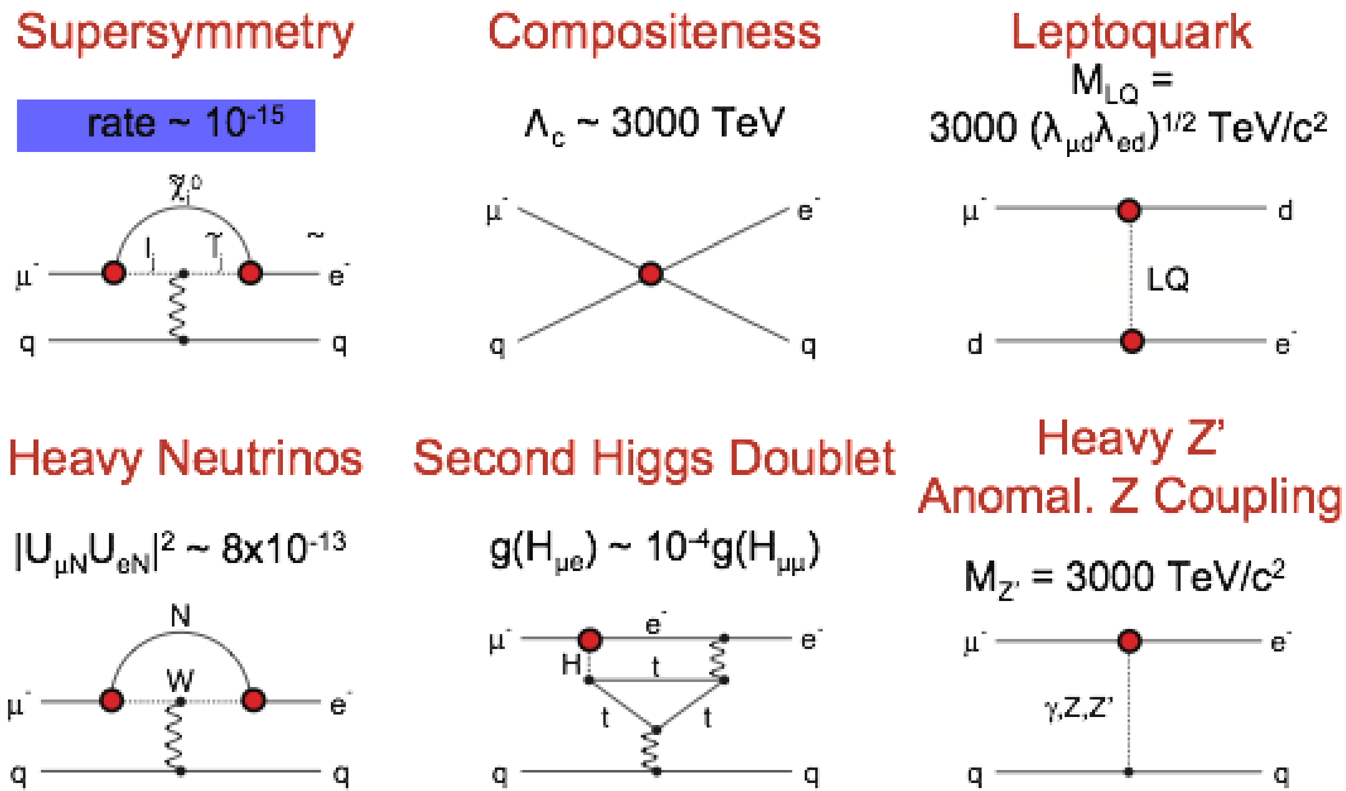
Calibration of the Hall probe: B vs V



Temperature dependence at $B \approx 0$



New physics



also see Flavour physics of leptons and dipole moments, arXiv:0801.1826
and Marciano, Mori, and Roney, Ann. Rev. Nucl. Sci. 58, doi:10.1146/annurev.nucl.58.110707.171126